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RECONSTRUCTING THE BIOLOGICAL INVASION OF EUROPEAN WATER-HOREHOUND, *LYCOPUS EUROPAEUS* (LABIATAE), ALONG THE ST. LAWRENCE RIVER, QUÉBEC

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ABSTRACT. In Québec (Canada), one of the most recently introduced exotic wetland plants is European water-horehound (*Lycopus europaeus*). The first specimens were discovered in 1963 near Montréal. In this study, we used herbarium specimens and conducted field surveys to reconstruct the history of the invasion of European water-horehound in Québec, and to accurately determine its current northeastern distribution. Few European water-horehound specimens were collected before 1970. However, between 1970 and 1974, the range of European water-horehound expanded 380 km northeastward from Sorel to Trois-Pistoles River. In 1999, the northeastern distribution limit of European water-horehound was at Bic Provincial Park, 65 km northeast of Trois-Pistoles River. Between 1963 and 1974, European water-horehound spread rapidly along the St. Lawrence River (45 km/yr.), which was probably related to the fact that seeds remain viable after floating. Between 1974 and 1999, it spread more slowly to the northeast of Trois-Pistoles River (3 km/yr.). The limited range expansion of European water-horehound in eastern Québec between 1974 and 1999 suggests that the salinity of surface waters, and more particularly the scarcity of coastal or riverine marshes east of Rimouski, prevented populations from establishing in the estuarine part of the St. Lawrence River.

Key Words: *Lycopus europaeus*, European water-horehound, Québec, St. Lawrence River, biological invasion, exotic species

In North America, invasion by exotic species is considered to be one of the main threats to preserving the integrity of ecosystems. In the United States alone, approximately 50,000 nonindigenous species cause major environmental damage and financial losses totaling US$137 billion per year (Pimentel et al. 2000). More than 5000 introduced plant species are now naturalized in North American ecosystems. Several of these plant species are problematic. For example, control costs and forage losses associated with purple loosestrife (*Lythrum salicaria* L.) have been estimated at US$45 million in the United States (Pimentel et al.

2000). It is therefore important to understand the mechanisms underlying successful plant invasions, and to develop models to predict the spread of invaders. Such models are useful for improving management plans that have been established to minimize the impacts of invasive species on natural ecosystems (Rejmánek and Richardson 1996).

One of the key components in modelling is the rate at which a species spreads, or the distance its range expands each year, indicated by newly established individuals outside the distribution range of a species (Lonsdale 1993). Rates of spread for plants are highly variable, and mainly depend on autecological characteristics of species and dispersal vectors. For example, between 1970 and 1984, the sedge *Carex praegracilis* W. Boott (a native species in North America) migrated eastward from Illinois, Indiana, and Michigan to New England states at a rate of 73 km/yr. This very rapid expansion rate was probably related to the development of highway networks, since this species is adapted to open and saline habitats commonly found along roads (Reznicek and Catling 1987). On the other hand, the rate of spread for the woody weed species *Mimosa pigra* L. in northern Australia (an exotic species in that country) was only 0.076 km/yr. between 1979 and 1985. Nevertheless, this rate is considered to be rapid for this pest species in Australia (Lonsdale 1993).

Wetland plant species usually spread rapidly because water is an effective dispersal vector (Catling and Porebski 1995; Lonsdale 1993; Pysek and Prach 1995). Wetland exotic plants are also among the most aggressive invaders and have dramatically changed the vegetation of many marshes at temperate latitudes. Several species are known to reduce the biomass of native plants, contribute to filling in small ponds, and form almost monospecific plant communities (Galatowitsch et al. 1999). In Québec (Canada), one of the most recently introduced exotic wetland plants is European water-horehound (*Lycopus europaeus* L., Labiatae). The native distribution range of this species is in Europe and western Asia (Stuckey and Phillips 1970). European water-horehound is a medium-sized plant, 0.4–1 m in height, copiously pubescent, with toothed leaves 4–12 cm long and 1.5–5 cm wide (Henderson 1962). This species is very similar to the widespread native American water-horehound (*L. americanus* Muhl.), but *L. europaeus* can be easily distinguished by its pubescent leaves (Scoggan 1979). Both species colonize marshes and drainage

ditches, as well as the shores of ponds, lakes, and rivers (Fleurbec 1987; Stuckey and Phillips 1970). The range of American water-horehound extends from British Columbia to Newfoundland, and from James Bay to Texas (Fleurbec 1987). European water-horehound was introduced into North America about 1860, probably in Virginia. Populations are now widespread along the Atlantic coast, from North Carolina to Nova Scotia. Numerous populations are also located along the shores of Lake Erie, Lake Ontario, and the St. Lawrence River. The introduction of European water-horehound into the Great Lakes–St. Lawrence River system (about 1903) and along the Atlantic coast of the United States were probably distinct events related to the release of ship's ballast (Stuckey and Phillips 1970).

The occurrence of European water-horehound in Québec is recent. The first specimens were discovered in 1964 near Valleyfield (Figure 1; Rousseau 1968). In 1974, Gauthier (1977) established its northeastern distribution limit at the mouth of Trois-Pistoles River (48°06′N, 69°14′W). On the shores of the St. Lawrence River, European water-horehound populations have mainly been found in marshes located in the supralittoral zone, and in the upper part of the intertidal zone (Chrétien 1994; Gauthier and Lavoie 1975). Stuckey and Phillips (1970) suggested that this plant was migrating down the St. Lawrence River, but there has been no historical reconstruction of the spread of European water-horehound in Québec that could be used to substantiate this assertion. In this study, we used herbarium specimens and conducted field surveys to reconstruct the history of the invasion of European water-horehound in Québec, and to accurately determine its northeastern distribution limit. We also calculated the rate at which this species has spread since its introduction into the province. Since water is probably the main dispersal vector for this species (Fleurbec 1987), we hypothesized that European water-horehound has spread along the St. Lawrence River at a rapid and constant rate over the last 35 years.

MATERIALS AND METHODS

To reconstruct past and recent distribution ranges for European water-horehound in Québec, we gathered information on all herbarium specimens of this species collected in the province. Herbarium specimens were requested from a total of eight herbaria:

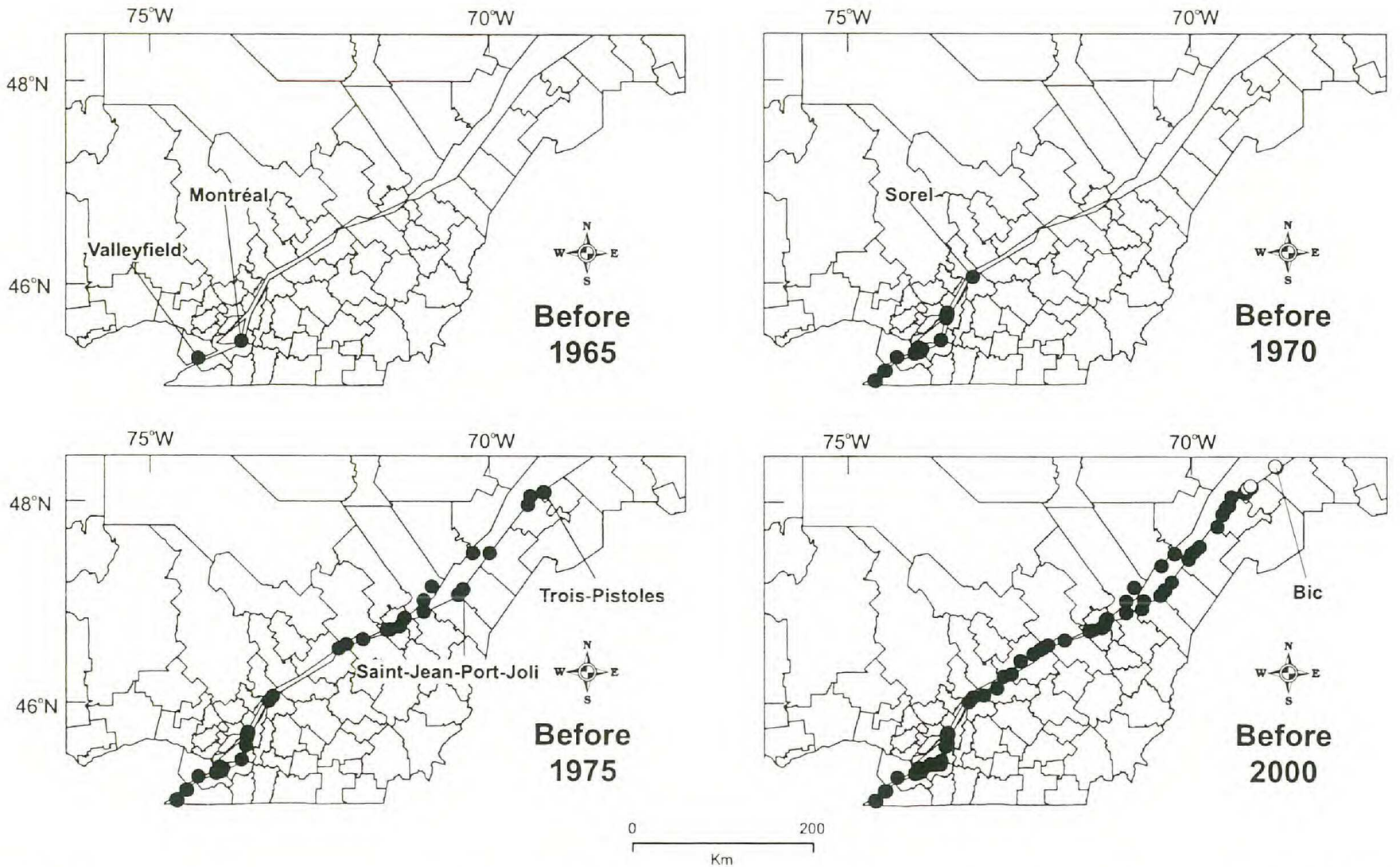

Figure 1. Location of European water-horehound (*Lycopus europaeus*) herbarium specimens collected in Québec before 1965, 1970, 1975, and 2000, respectively. Black dot: specimen found in herbarium; white dot: specimen collected during this study (August 1999). Subdivisions = municipal regional counties.

CAN, DAO, MT, MTMG, QFA, QSA, QUE, and SFS (*Index Herbariorum* website: www.nybg.org/bsci/ih/ih.html). Each herbarium specimen was checked for possible misidentification, and we noted the specimen number, collection location and year, and habitat characteristics. Data on specimens were incorporated into a geographical information system to accurately reconstruct the evolution of European water-horehound's distribution range during the 20th century in Québec. We also examined herbarium specimens of *Lycopus americanus* from QFA (which has the biggest collection of *L. europaeus* and *L. americanus* from different locations in Québec) to find misidentified European water-horehound specimens.

To accurately determine the northeastern distribution limit of the species in Québec in August 1999, we surveyed the south shore of the St. Lawrence River between Trois-Pistoles River (the known distribution limit) and Sainte-Anne-des-Monts (49°08′N, 66°30′W), 300 km to the northeast. This region corresponds to the regional landscape unit of Rimouski (Robitaille and Saucier 1998). The mean annual temperature in the region is 2.5°C, and mean annual precipitation totals 900 mm. The salinity of the St. Lawrence River near Trois-Pistoles River and Sainte-Anne-des-Monts is 24‰ and 27‰, respectively. Approximately 67% of the region is comprised of agricultural land (Bourget 1997; Robitaille and Saucier 1998). We did not survey the steep north shore of the St. Lawrence Estuary because there are very few suitable habitats (coastal marshes) for European water-horehound along this shoreline. Furthermore, surface currents, which are likely to disperse plant seeds, flow upstream near the north shore of the St. Lawrence River (Centre Saint-Laurent 1996). Consequently, an expansion of European water-horehound's distribution range is unlikely to occur along the north shore of the St. Lawrence River Estuary.

Between Trois-Pistoles River and Sainte-Anne-des-Monts, sampling points were chosen systematically every 5 km along the shore of the St. Lawrence River. At each sampling point, where access to the shore was possible, we surveyed the shore of the river (the supralittoral zone and the upper part of the intertidal zone) for a one-hour period to detect the presence of European water-horehound populations. Once a population was discovered, the following information was noted: 1) the exact location of the population on the shore, 2) the number of individuals in the pop-

ulation, and 3) any associated vascular plant species. Furthermore, one or two specimens were collected for further identification in the laboratory. All collected specimens are stored in the Louis-Marie Herbarium (QFA) at Université Laval. All sampling points located within a 100-km distance from the last sampling point with a European water-horehound population were visited. Beyond the 100-km distance, only sampling points with habitats appropriate for the establishment of European water-horehound populations (i.e., marshes located in the supralittoral zone, and/or in the upper part of the intertidal zone, or the mouth of freshwater tributaries) were visited.

RESULTS

One hundred and ninety-nine (199) herbarium specimens (including those collected in this study) from 101 locations were carefully examined. Data from these specimens were used to accurately reconstruct the recent change of European water-horehound's distribution in Québec (Figure 1). We discovered that the oldest specimen was not sampled in 1964, but rather in 1963 on the south shore of Île-des-Sœurs, near Montréal (45°26′N, 73°33′W). This specimen was originally misidentified as *Lycopus americanus*. Few *L. europaeus* specimens were collected before 1970; however, between 1970 and 1974, the range of European water-horehound expanded 380 km northeastward from Sorel to Trois-Pistoles River, which represents a very rapid rate of spread (95 km/yr.).

Before this study, no specimen of European water-horehound had been collected northeast of Trois-Pistoles River. In August 1999, we discovered three populations beyond Trois-Pistoles River (Figure 2):

1. Trois-Pistoles Bay (48°07′N, 69°10′W)
2. Anse-des-Riou (48°09′N, 69°07′W)
3. Anse-à-l'Orignal (48°21′N, 68°46′W), in Bic Provincial Park

These three populations were located 8, 12, and 65 km northeast of Trois-Pistoles River, respectively. These European water-horehound populations (10–15 individuals) were found in the supralittoral zone at the upper edge of *Spartina alterniflora* Loisel. marshes. They were also located very close to small freshwater

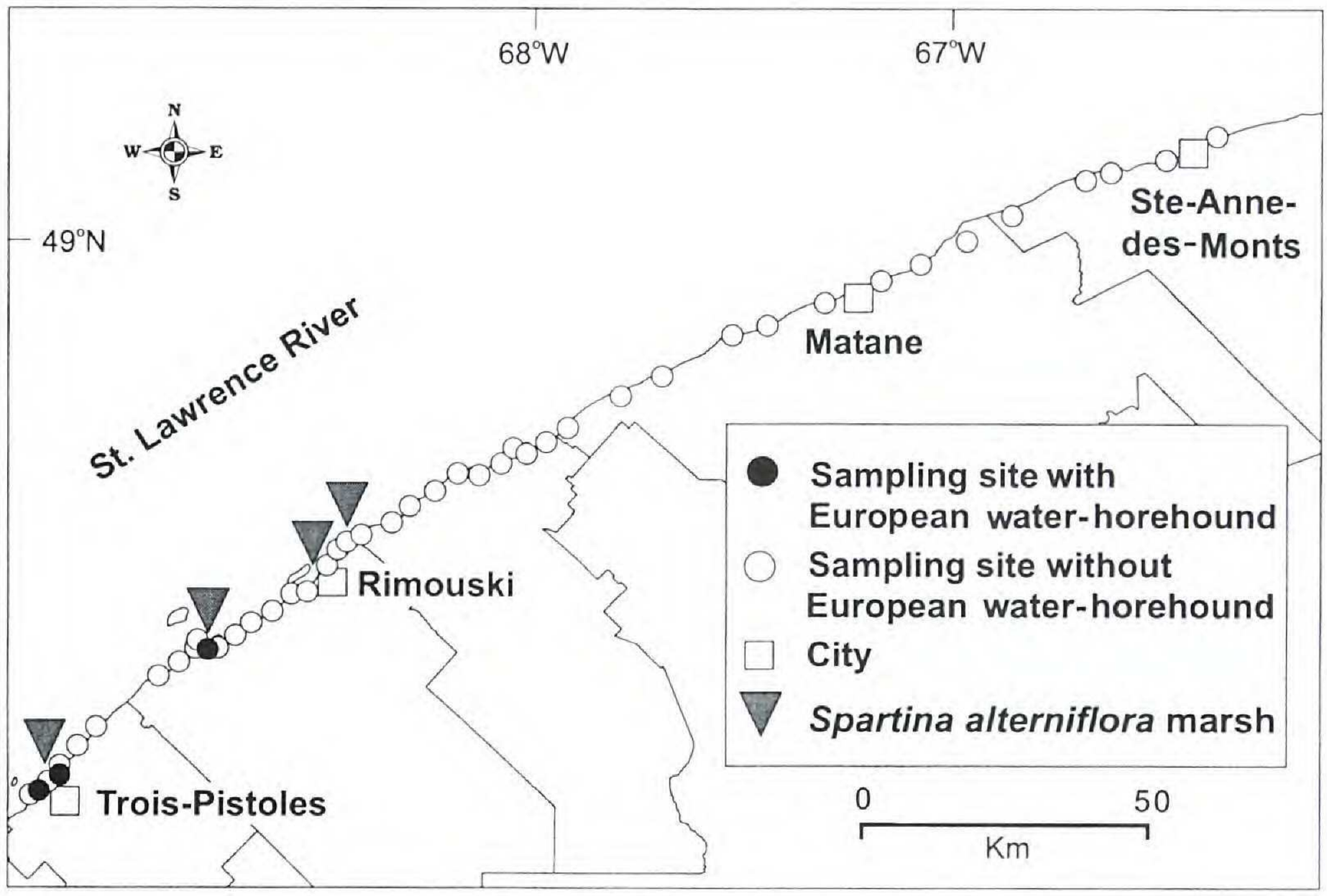

Figure 2. Sampling sites along the shore of the St. Lawrence River that were visited in August 1999 to determine the northeastern distribution limit of European water-horehound (*Lycopus europaeus*) in Québec, and location of *Spartina alterniflora* salt marshes in the area. Subdivisions = municipal regional counties.

brooks, and on silt or clay soils. Populations were surrounded by *Typha angustifolia* L. or *Lythrum salicaria* communities. Between 1974 and 1999, the rate of expansion of European water-horehound northeast of Trois-Pistoles River was only 3 km/yr.

DISCUSSION

Between 1963 and 1974, European water-horehound spread along the St. Lawrence River at a rate of 45 km/yr. During the last 25 years, the species spread from Trois-Pistoles River to Bic Provincial Park at a rate of only 3 km/yr. What could explain this difference? First, it is possible that the expansion of European water-horehound's distribution range northeast of Trois-Pistoles River was limited by the increasing salinity of estuarine waters. For example, upstream from Saint-Jean-Port-Joli (Figure 1; 47°10′N, 70°15′W), where the salinity of the St. Lawrence River surface water is < 1–2‰, European water-horehound populations are located in the supralittoral and intertidal zones (Chrétien 1994; Gauthier 1977; numerous herbarium specimens). Down-

stream from Saint-Jean-Port-Joli, the salinity of surface water increases rapidly (from 1–2 to 15‰ over a 60-km distance), and European water-horehound populations are located only in the supralittoral zone (i.e., outside the zone regularly flooded by brackish water tides; Bourget 1997). Second, herbarium specimens and the field survey conducted in 1999 suggest that in the estuarine part of the St. Lawrence River, European water-horehound populations are located only in large *Spartina alterniflora* marshes. These marshes are very small and scarce northeast of Rimouski (Figure 2; Centre Saint-Laurent 1996). Third, the reconstruction of the spread of an invading species using herbarium specimens is highly dependent on the occurrence of field surveys conducted during different periods, and, in this case, on the ability of botanists to distinguish *Lycopus europaeus* in the field from the closely related *L. americanus*. For example, more than 20% of *L. europaeus* herbarium specimens that were examined in this study were originally misidentified as *L. americanus*, and were correctly identified only in 1978–1979 (most of them reviewed by J. Cayouette, DAO). However, no *L. europaeus* specimen was found in the *L. americanus* collection of QFA (206 specimens). Our reconstruction of the spread of European water-horehound in Québec should nevertheless be considered with some degree of caution.

Whatever the exact rate of spread of European water-horehound along the St. Lawrence River, our data clearly indicate that the spread of this exotic species was particularly rapid in Québec. For example, the maximum rate of spread of another exotic wetland plant species, *Hydrocharis morsus-ranae* L., was only 16 km/yr. between 1939 and 1994 within the Great Lakes–St. Lawrence River system. Seeds of *H. morsus-ranae* are dispersed by water, birds, and boats (Catling and Porebski 1995). No animal vector is known for European water-horehound, but the fact that seeds remain viable after floating for 12 to 15 months (Stuckey 1969) certainly facilitated the rapid spread of this species over long distances in Québec.

The limited range expansion of European water-horehound in eastern Québec between 1974 and 1999 suggests that the salinity of surface waters, and more particularly the scarcity of coastal or riverine marshes east of Rimouski prevented populations from establishing in the estuarine part of the St. Lawrence River. However, populations established upstream from Saint-Jean-Port-Joli

seem to be expanding, and *Lycopus europaeus* may eventually replace the closely related native species *L. americanus* as one of the main species of the supralittoral and intertidal zones (Chrétien 1994). European water-horehound is still absent from large tributaries of the St. Lawrence River, and its further expansion into these rivers should be attentively surveyed.

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